TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

2.2 REACTOR COOLANT PUMPS

Learning Objectives:

1. State the purposes of the Reactor Coolant Pump (RCP).
2. Describe the flow paths through the RCP.
3. Explain how the RCP seal minimizes leakage of reactor coolant to the containment building atmosphere.
4. State the safety-related function of the RCP motor flywheel.
5. State the purposes of the RCP motor anti-reverse rotation mechanism.
6. State the purpose of the reactor coolant pump instrumentation.

2.2.1 Reactor Coolant Pump Purposes

The purposes of the RCPs are:

1. To provide the forced circulation of reactor coolant for the removal of core heat,
2. Improve departure from nucleate boiling ratio during loss of all reactor coolant pump motor power, and
3. To provide energy to heat up the RCS from ambient temperature to greater than the minimum temperature for criticality prior to reactor startup.

2.2.2 Introduction

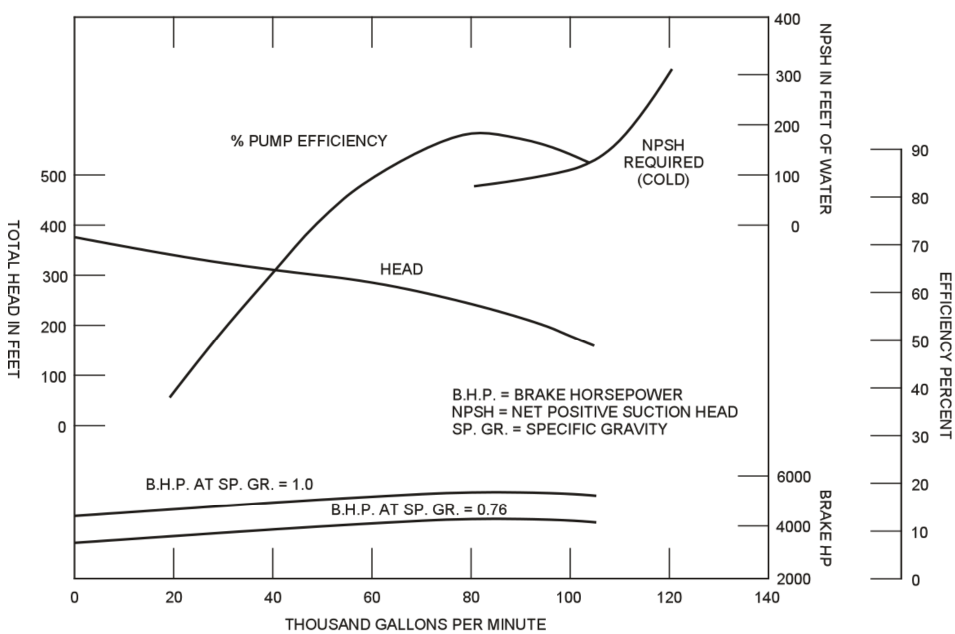

Figure 2.2-1 Reactor Coolant Pump Operating Curve

The four RCPs circulate reactor coolant through the core at a rate of 122 x 10^6 lbm/hr. This flow rate provides heat removal for the 2700 megawatt rating of the core. Each reactor coolant pump is a vertical shaft, single suction, single stage centrifugal pump with a flow rate of 81,200 gpm (Table 2.2-2). The pump is driven by a squirrel cage induction motor powered from the 13.8 kV non-vital ac distribution system. All four pumps must be running for critical operations. Figure 2.2.1 illustrates the pump characteristics.

2.2.3 Pump Construction

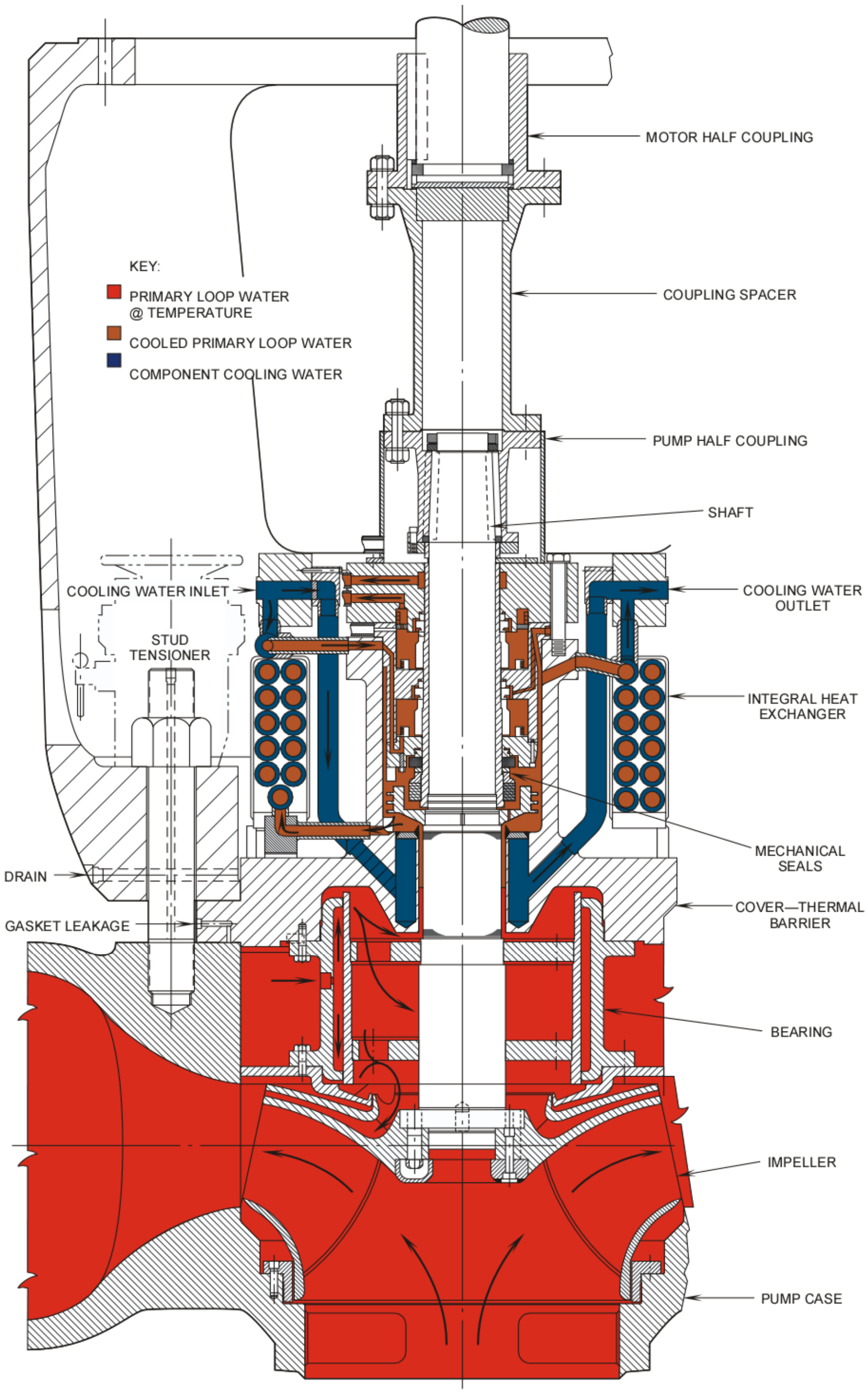

Figure 2.2-2 Reactor coolant Pump Assembly

The RCPs are vertical shaft, single-suction, single-stage, centrifugal pumps which are manufactured by Byron Jackson, a division of Borg Warner. The main components of the pump are the pump case assembly, the pump cover and heat exchanger assembly, the driver mount, the rotating element assembly (shaft, impeller, and coupling) and the shaft seal assembly.

The pump case assembly consists of the pump case, the case wear ring, and various gaskets and fasteners. The pump case forms the volute of the pump which is designed to convert the velocity head of the coolant discharged from the pump impeller into pressure head potential. The casing wear ring is an interface medium between the pump impeller and the casing. Because the wear ring metal is not as hard as the metal from which the impeller is made, the wear ring preferentially wears during use, thereby protecting the integrity of both the impeller and the casing.

The pump cover and heat exchanger assembly consists of a metal enclosure located above the pump impeller and supports the components above it (the heat exchanger and the hydrostatic bearing). The heat exchanger's tubes are segregated into two banks which are piped in parallel and arranged concentrically about the pump shaft. The heat exchanger tubes consist of a pipe of smaller diameter contained within a pipe of a larger diameter so that reactor coolant, which is at a high pressure, can flow through the inner pipe and Component Cooling Water (CCW), which is at a lower pressure, can flow through the annular region between the inner and outer pipes.

The hydrostatic bearing positions the pump shaft in the horizontal direction and is self aligning. Bearing self alignment is achieved by directing impeller discharge pressure against the surface of the bearing journal balance plate which moves the bearing journal in the horizontal direction. The hydrostatic bearing is mechanically restrained in the vertical direction by attaching it to the pump cover.

Metallic O-rings and studs provide a seal between the pump casing and the casing cover. A passage between the two O-rings is connected to piping which is routed to the containment sump. If the inside O-ring fails, hot reactor coolant will flow to a Resistance Temperature Detector (RTD) that is located in the drain path, causing an increased output from the RTD, resulting in an alarm in the control room. The outside O-ring prevents leakage from the RCS in this event.

The rotating element assembly consists of the pump shaft with its bearing journal, the impeller, the auxiliary impeller, the recirculating impeller, the pump half coupling, the thrust disc, the motor half coupling and the rotating pump seal package components. The pump shaft is the principal rotating element to which the other components are attached. The pump shaft's motion is restrained in the horizontal direction by the bearing journal, which is attached to the shaft immediately above the pump auxiliary impeller.

The auxiliary impeller supplies pressure to the self-aligning journal bearing and a small amount of flow to the pump seals via the thermal barrier. The pump half coupling, motor half coupling, and thrust disc are located at the top of the pump shaft. They connect the pump rotating element assembly to the motor shaft.

When assembled for operation, the coupling components of the rotating element assembly transmit torque from the motor to the pump, and transfer vertical thrust from the pump shaft to the motor thrust bearing. The spacer, which connects the motor half coupling to the pump half coupling, can be removed to permit access to the shaft seal without removal of the motor. The setting of the adjusting cap and the thrust disc/spacer ring determine the axial alignment of the rotating components.

2.2.4 Reactor Coolant Pump Seal Assembly

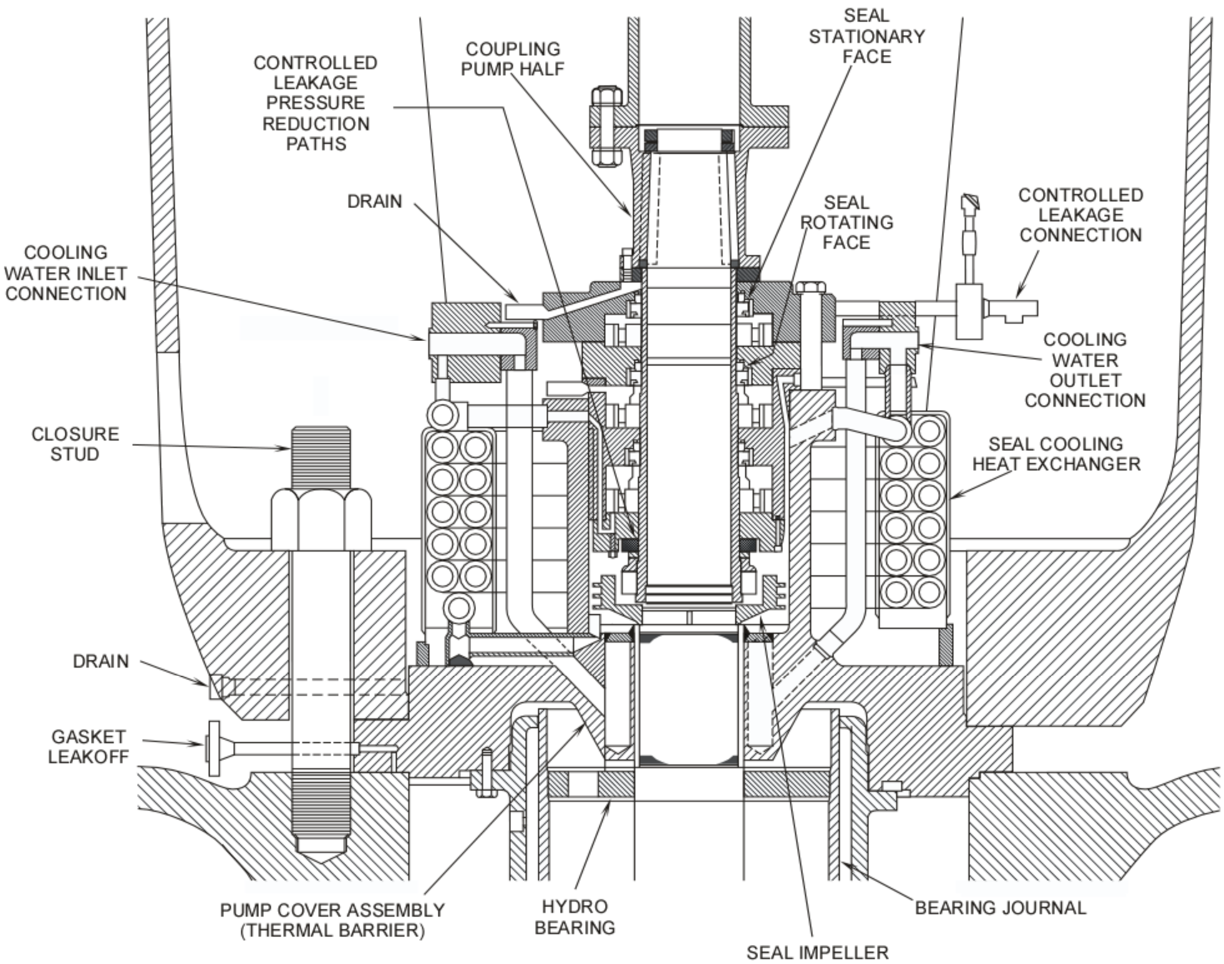

Figure 2.2-3 Reactor Coolant Pump Seal Assembly

The RCP seal assembly consists of a concentric tube heat exchanger, a shaft mounted auxiliary impeller, four mechanical seals, and seal pressure breakdown devices. The seal assembly functions to minimize the leakage of reactor coolant past the shaft and into the containment building.

The mechanical seals are lubricated and cooled by 1.0 gpm of Controlled reactor coolant Bleed-Off (CBO). Reactor coolant enters the seal area through the region between the labyrinth seal/thermal barrier and the shaft. In this process, some of the thermal energy contained in the reactor coolant is removed by CCW supplied to this region of the pump. The labyrinth seals reduce the RCS working pressure, which was increased by the main and auxiliary impellers, back to RCS pressure (2250) to minimize the mechanical seal wear which would otherwise occur if the seals were operated at a higher pressure.

The seal package for the RCP consists of four mechanical seals. Three of these seals are used to contain reactor coolant pressure while the fourth is used as a vapor seal. Each of the four seals is able to withstand full system pressure. Each mechanical seal consists of a shaft mounted titanium carbide rotating face and a stationary graphite face.

Springs on the rotating face keep the seal faces aligned. Breakdown orifices are installed in parallel with the first three seals and are used to set the operating differential pressure (~700 psid) of each seal. Of the one gallon per minute that leaves the recirculation area, approximately 99% passes through the orifice breakdown devices, and the other 1% passes between the seal faces for lubrication.

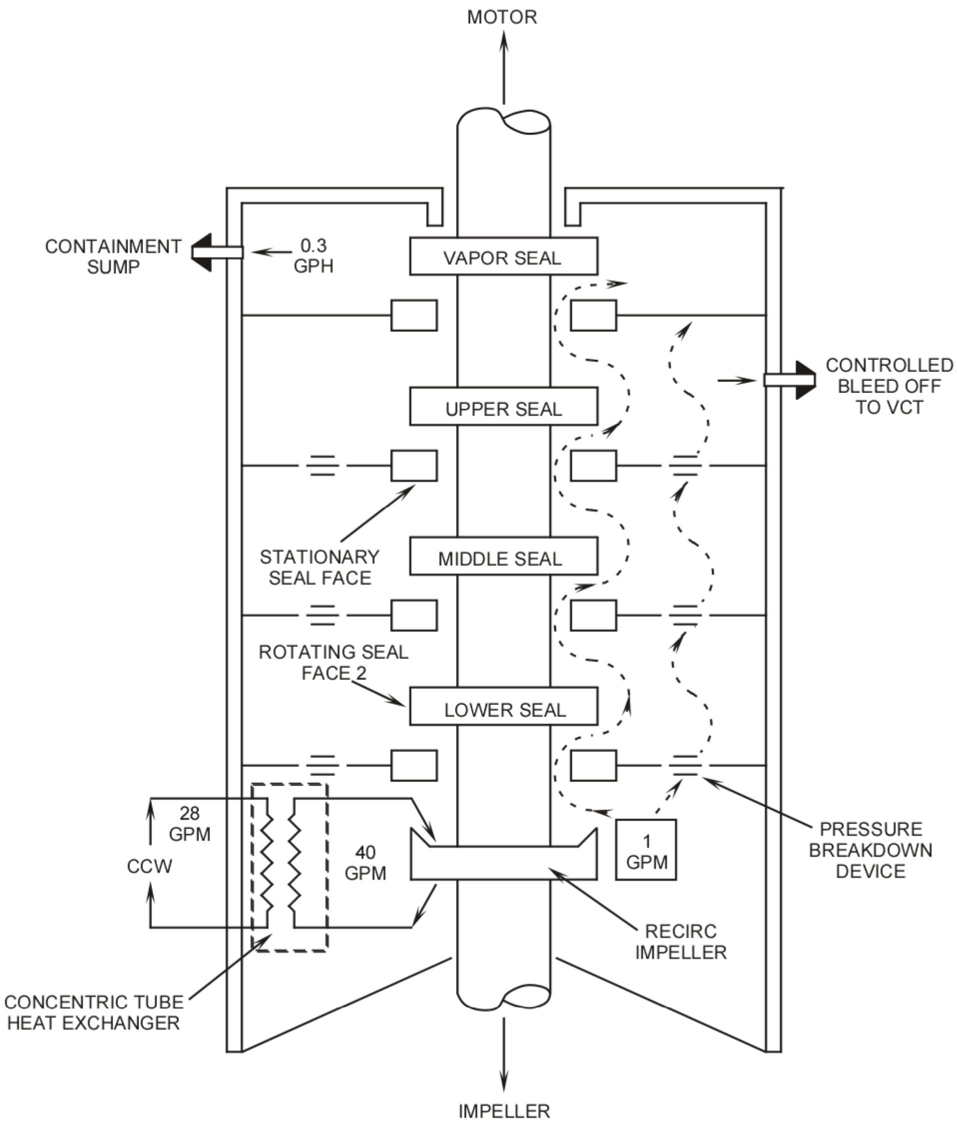

Figure 2.2-4 Simplified Seal Diagram

Figure 2.2-4 provides a simplified diagram of the pump seals and breakdown devices. As shown on the drawing, one gpm of flow enters the lower seal and breakdown device at RCS pressure (2250 psia). The majority of flow passes through the device to the middle seal area and the remainder passes between the seal faces of the lower seal. Water at a pressure of ~1500 psia travels in the same manner through the middle seal. Finally, the inlet pressure to the upper seal is ~750 psia and the flow through this seal is identical to the flow through the lower and middle seals. Most of the water that passes through the seals is collected above the upper seal through the CBO line and routed to the Volume Control Tank (VCT). Approximately 0.3 gallons per hour will pass between the rotating and stationary faces of the vapor seal and into the containment sump. As described above, the leakage up the shaft is forced to take a tortuous path through the seal faces thus the quantity of leakage is minimized.

The RCP seal assembly description provided above should be considered to be typical of a Byron Jackson pump installation. Competitive forces in the market place have brought some amount of choice to utilities seeking promises of improved seal performance. The inspector should determine the origin, construction and operational features of the seals used at their individual locations

2.2.5 Flow Paths Through the RCP

There are four flow paths through each RCP:

1. RCS flow to the reactor vessel through the RCP impeller from the steam generator,
2. The auxiliary impeller, mounted on the back of the RCP impeller, draws coolant from the RCP journal bearing area and returns it to the discharge of the main pump impeller.
3. Seal cavity recirculation flow generated by the seal water recirculating impeller which flows from the seal cavity to the inner pipe of the integral heat exchanger tubes and is then discharged to the seal pressure breakdown devices and the seals themselves, and
4. The CCW flow, which is divided into two streams: one of which cools the thermal barrier and the second of which passes through the annular region between the inside and outside pipes that form the integral heat exchanger tubes, thereby removing heat from the seal area recirculation flow.

A portion of the seal cavity flow passes through the pressure breakdown devices, bypassing the seal faces, and is discharged as controlled bleed off to either the volume control tank or the Reactor Coolant Drain Tank (RCDT).

The seal area recirculating impeller delivers approximately 40 gpm of water to the integral heat exchanger. The recirculating water flow passes upward in a parallel path through the inner diameter integral heat exchanger tubes, which are arranged in two concentric tube banks. CCW flows in a downward direction through the annular region between the inner and outer diameter pipes which comprise the integral heat exchanger tubes, thereby removing heat from the recirculating water flow stream. The CCW from the thermal barrier and integral heat exchanger are combined at the heat exchanger's discharge, and the combined flow is returned to a CCW return header.

The recirculating water flow, which leaves the heat exchanger inside the tube bank, enters the seal cavity between the cover and the middle pressure breakdown device. The water flows toward the recirculating impeller past the low pressure breakdown device and is recirculated into the inner heat exchanger tubes. The recirculating water flow, which is cooled by the heat exchanger outside tubes, is directed into the lower pressure breakdown device where it is forced by differential pressure through three stages of pressure breakdown and cools the three upper seals as it flows out of the CBO.

The quantity of water which passes through the CBO discharge is approximately one gpm. CBO past the third seal, is ducted by a header to the VCT. Leakage past the fourth seal, the vapor seal, is directed to the containment sump. Less than 0.3 gallon per hour passes through this last seal.

Water from CCW cools the RCP and pump motor. CCW flow rate to each reactor coolant pump is 200 gpm, of which 45 gpm is directed to the seal area and 155 gpm is directed to the RCP motor. Both the upper and lower oil reservoirs in the pump motor have oil-to-water heat exchangers which are also cooled by CCW.

The seal area cooling water is further subdivided into two streams:

1. Seventeen gpm of CCW is used to cool the thermal barrier area, the labyrinth passageway through which the one gpm CBO enters the seal cavity area, and
2. Twenty-eight gpm of CCW is directed to the integral heat exchanger tubes through which the approximately 40 gpm of recirculation water passes.

CCW enters the integral heat exchanger at the top of the heat exchanger's inside and outside tube banks and flows in a downward direction through the annular region formed by the heat exchanger's double pipe tube arrangement. Recirculating water, contained in the inner pipe of the heat exchanger tubing, gives up heat energy to the cooler CCW. The integral heat exchanger is configured as a counter flow heat exchanger arrangement and the recirculating water flows in a direction opposite to that of the CCW. The counter flow configuration is more efficient than a parallel flow arrangement which allows a smaller heat exchanger to be used. The counter flow arrangement also minimizes the temperature differential between the recirculating water and component cooling water at the heat exchanger inlet, thereby reducing thermal shock to the heat exchanger components in this region.

2.2.6 Reactor Coolant Pump Motor

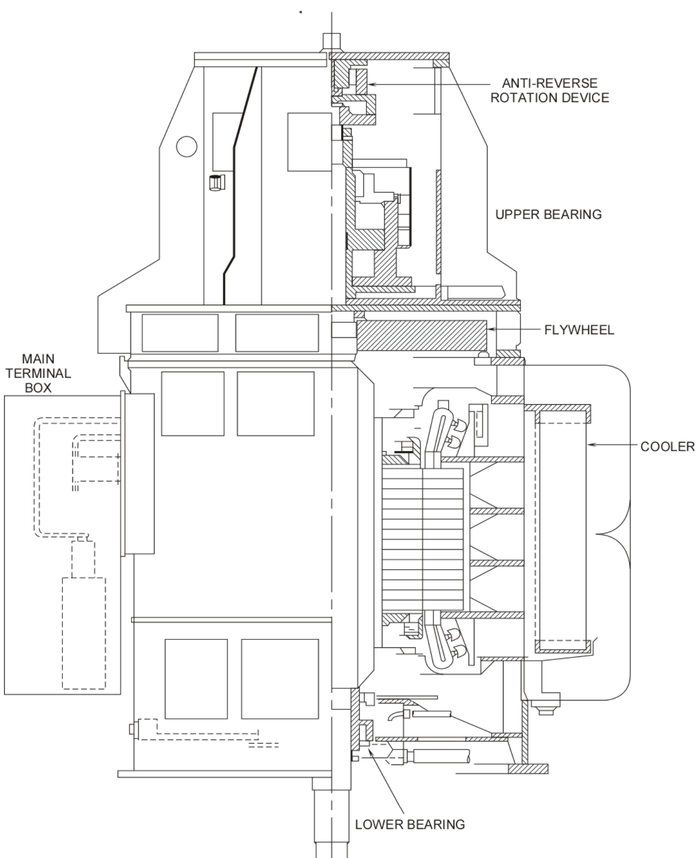

Figure 2.2-5 Reactor Coolant Pump Motor Assembly

The RCP motor is a vertical, solid shaft, three phase, squirrel cage induction ac motor. The major components of the motor are the rotor, stator, two radial bearings, a thrust bearing, flywheel, anti-reverse rotation device, and the motor air cooler.

The induction rotor and stator are of conventional design with a rotational speed of 900 rpm and are rated at 6000 horsepower. The motor is cooled by a rotor attached fan and the motor air cooler. The fan is mounted at the bottom of the rotor and draws containment building air across the motor air cooler. The air is discharged out the top of the motor. A CCW flow of 155 gpm cools the motor inlet air.

The motor radial bearings maintain

rotor alignment and are oil lubricated by a self contained oil reservoir and the rotational action of the bearing race. The thrust bearing is a Kingsbury double acting thrust bearing and along with the pump hydrostatic radial bearing supports the weight of the motor/pump. In addition, the thrust bearing compensates for thrusts caused by the hydraulic forces when the pump is operating. A high pressure oil lift pump forces oil under the thrust shoes to reduce torque during start-up. A low pressure oil pump is used to lubricate the anti-reverse rotation device during pump starting. Both pumps are stopped once the RCP reaches rated speed.

The RCP flywheel is installed on the motor rotor and functions to increase pump coast down time. The increase in flow coast down improves the Departure from Nucleate Boiling Ratio (DNBR) after a complete loss of pumping power event. Since this component is involved in reactor protection analysis, it is safety related and subject to integrity inspections.

The final motor component is the anti-reverse rotation device which serves two purposes. First, the anti-reverse rotation device minimizes motor starting torque. If a start of the pump is attempted when the pump is rotating in the reverse direction, the pump must be decelerated to zero speed and then accelerated in the correct direction to normal speed. The current required to decelerate and accelerate could cause damage to the motor and associated electrical cabling. Second, the anti-reverse rotation device minimizes reverse flow through an idle pump.

2.2.7 RCP Instrumentation

The four RCPs are equipped with instrumentation to detect and warn the operator of impending failure or abnormal operating conditions.

2.2.7.1 Pump Instrumentation

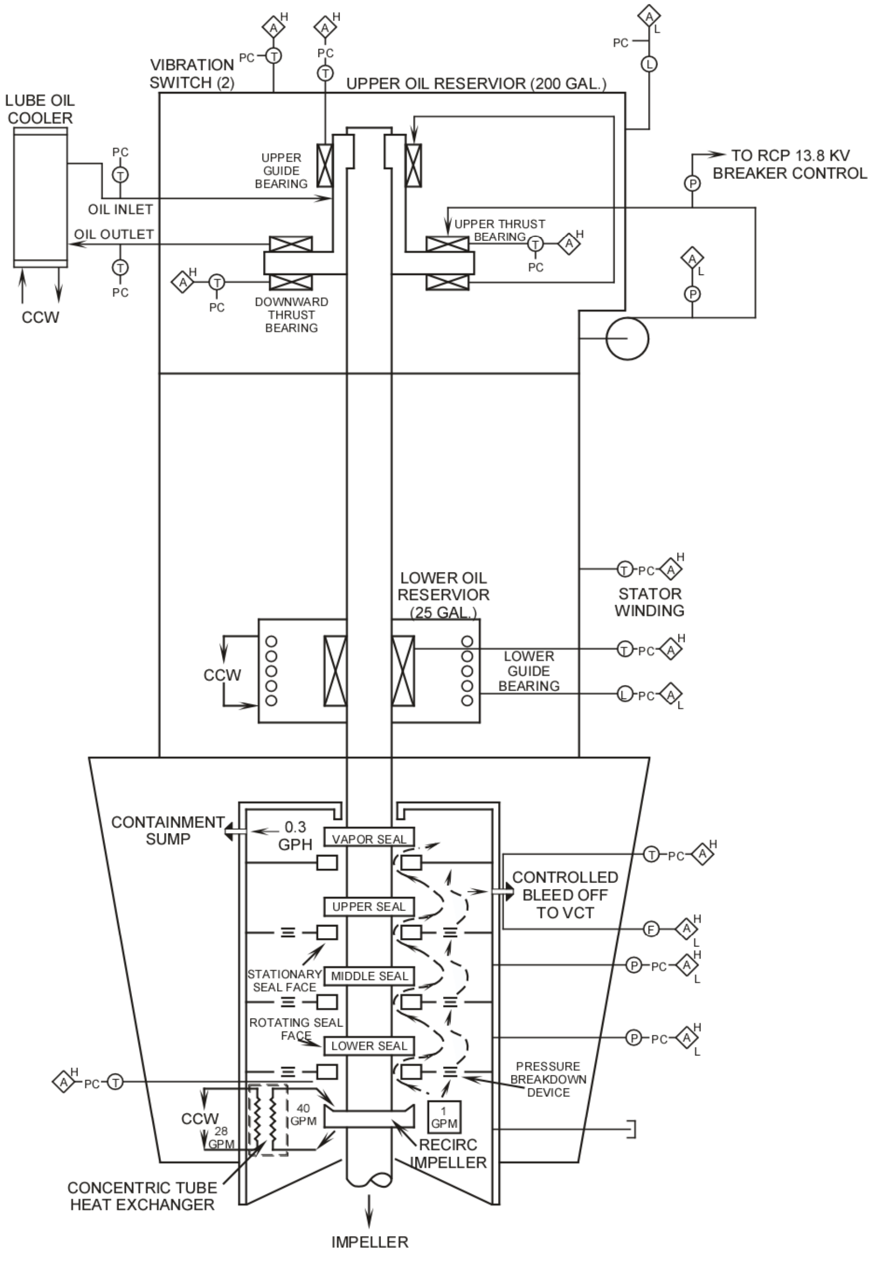

Figure 2.2-6 Reactor Coolant Pump Instrumentation

RCP instrumentation includes seal pressure and temperature, CBO flow and temperature and pump vibration indication.

The RCP seal system is monitored by three pressure detectors and one temperature detector. The RCP shaft seal assembly consists of four mechanical seals. The three full-pressure seals are mounted in series and each has a pressure detector that senses the pressure below the respective seal. The lower seal pressure detector is not indicated in the Main Control Room (MCR) since it should equal RCS pressure, however, a signal is sent to the plant computer. The middle and upper seal pressure detectors send signals to individual pressure indicators in the MCR as well as to the plant computer. The middle seal and upper seal pressure detectors actuate respective RCP seal temperature/pressure alarms in the MCR.

These indications can be used by the operating staff to determine seal failures. The following table gives typical pressures for various seal failures, assuming a normal RCS pressure of 2250 psia.

Table 2.2-1 Seal Pressures

Failed Seal	Middle Cavity Pressure	Upper Cavity Pressure	Vapor Seal Pressure
None	1500	750	VCT
Lower	2250	1125	VCT
Middle	1125	1125	VCT
Upper	1125	VCT	VCT

When any seal is lost, the differential pressure across the remaining seals increases, and CBO flow increases. An alarm set at 1.25 gpm (normal flow = 1 gpm) will alert the operator to the possibility of a seal failure. Due to the increased flow, controlled bleed off temperature will also increase.

While a controlled bleed off temperature may be caused by a seal failure, loss of CCW to the seal area heat exchanger will also cause an increase in this temperature as well as the inlet temperature to the seal area. The RCP seal area temperature detector senses the outlet temperature of the primary coolant from the lower seal. The temperature detector provides indication and an RCP seal temperature/pressure alarm in the MCR.

The CBO flow from the RCP seals is sent to the VCT in the Chemical And Volume Control System (CVCS). The flow leaving the pump seals is monitored by flow and temperature detectors. The CBO flow detector provides high and lowflow alarms in the MCR. A CBO flow temperature detector provides a signal to the plant computer and actuates a high temperature alarm in the MCR.

Each RCP has two proximity probe detectors installed in the shaft coupling area to provide eccentricity and vibration alarms to the MCR.

2.2.7.2 Motor Instrumentation

RCP motor instrumentation includes stator winding temperature, guide bearing temperature, oil reservoir levels, thrust bearing temperature, motor vibration, lube oil cooler temperature and oil lift system instrumentation.

Each RCP has six stator winding temperature detectors. During plant testing, the temperature detector that consistently has the highest temperature indication is selected to provide input into the plant computer. The signal from this temperature transmitter also actuates a high temperature alarm in the MCR.

The upper and lower RCP motor guide bearings each have one temperature detector. Each detector supplies a signal to the plant computer and also actuates a high temperature alarm in the MCR. The RCP pump guide bearing temperature is not monitored by any instrumentation.

The oil level in the upper and lower oil reservoirs of each RCP motor are monitored by two level detectors. Each detector sends a signal to the plant computer and also actuates an oil reservoir low alarm in the MCR.

The upward and downward RCP motor thrust bearings each have one temperature detector. Each detector supplies a signal to indication in the MCR, the plant computer and a thrust bearing high temperature alarm in the MCR.

Each RCP has two vibration switches located on top of the pump motor housing. Each switch supplies an input to the plant computer and actuates a RCP vibration alarm in the MCR. The alarm is common to both switches.

The RCP lube oil cooler has a temperature detector on the cooler oil inlet and outlet lines. The temperature detectors sense the lube oil temperature and send signals to the plant computer. There are no alarms associated with these instruments.

The RCP oil lift system has a local pressure indicator and two pressure switches installed on the oil lift pump discharge header. One pressure switch closes contacts in the RCP breaker permissive circuit to allow closing the breaker. The other pressure switch actuates an oil lift pump low pressure alarm in the MCR.

2.2.8 Reactor Coolant Pump Circuitry

The Oil Lift Pump (OLP) must be in operation at the time of RCP startup and must remain in operation for 30 seconds after RCP startup. The oil lift system uses a separate hydraulic piston pump to lubricate the thrust bearings and upper guide bearings during RCP motor start up. While the RCP is running, the thrust bearing thrust runner acts as the oil pump. The OLP is interlocked with the RCP bus breaker closing circuit so that sufficient oil lift pressure must be available prior to closing the breaker. A timing relay in the RCP bus breaker control circuit automatically secures the OLP after the RCP has been running for 30 seconds.

A device called a synchronizing stick must be inserted into a synchronizing jack at the RCP control section of the main control boards to complete the RCP circuit breaker closing circuit. The synchronizing stick also connects the RCP available power supplies to a synchroscope when used at the electrical distribution control panel so that the RCP bus can be deenergized, or a paralleling operation can be performed with the alternate power supply. The synchronizing stick is normally housed at the electrical distribution control panel.

The last condition that must be satisfied within the control circuitry to start a RCP is sufficient CCW pressure to close a pressure switch contact in the RCP bus breaker closing circuit. The CCW interlock ensures that stator, lube oil and seal cooling are available prior to starting the pump.

2.2.9 Reactor Coolant Pump Operations

2.2.9.1 Normal Operations

Prior to starting any RCP, a steam bubble is formed in the pressurizer and RCS pressure is increased to ~270 psia. This value of pressure will satisfy the minimum recommended pressure for proper seal operation (200 psia) and will ensure that the Net Positive Suction Head (NPSH) of 266 psia for a flow rate of 120,000 gpm is satisfied (This flow rate is above the value given in section 2.2.2. 120,000 gpm is the flow rate with only one RCP operating). After pressurizing to the desired pressure, a RCP in each loop is run for 3 to 5 minutes, and the RCS is vented. When venting operations are completed, three of the RCPs are started, and the frictional energy added by the pump impeller (3.3 Mwt/RCP) heats up the RCS.

Because the coolant is very dense when the pumps are first placed in service, each pump will initially require approximately 6000 horsepower. As the coolant temperature increases, pump power requirements decrease to 4500 horsepower at operating temperatures. When coolant temperature increases above 500°F, the fourth pump is placed in service. The 500°F administrative limit is imposed to prevent a high flow rate of dense coolant from lifting fuel assemblies. If the fuel assemblies are lifted, fretting of the fuel element cladding by an adjacent assembly could cause fuel pin clad failure. Above 500°F, the density of the coolant has decreased to a point where full RCS flow will not lift the fuel assemblies.

During power operations, all RCPs are required to be in service providing forced circulation of the reactor coolant. If a RCP trips at power levels greater than 10^{-4}%, a reactor trip will occur on low RCS flow. At power levels of less than 10^{-4} %, the low RCS flow reactor trip may be bypassed.

When the plant is to be shutdown and cooled down, a RCP in each loop is stopped after the reactor is shutdown. This minimizes the heat input into the RCS.

2.2.9.2 Loss of Flow Events

Various loss of coolant flow accidents were analyzed by Combustion Engineering (CE), and the case of the single pump shaft seizure provides the most potential for core damage. While it is definitely possible for a four-pump loss of flow incident (due to loss of off site power), it is not considered credible for more than one pump to suffer shaft seizure simultaneously.

With a pump shaft seizure, reactor coolant flow rate drops by nearly 23% within two seconds after initiation. Calculations for this accident indicate that a minimum DNBR of 0.5 will be reached two seconds after shaft seizure. However, conservative estimates indicate that less than two percent of the fuel will actually experience DNBR.

The four pump (loss of off site power) loss of reactor coolant flow accident is actually less severe than the pump seizure because of the availability of the reactor coolant pump motor flywheels to provide coast down flow. By comparison with the pump seizure case, the flow rate for a four pump loss of flow is still greater than 88% of full flow at five seconds after the start of the incident. The minimum DNBR calculated is 1.3 and it occurs just less then three seconds after the start of the incident.

2.2.10 PRA Insights

From a risk standpoint, the RCP seal package is a major contributor. A failure of the seal package may lead to a small break loss of coolant accident which is one of the significant accident sequences listed in the Calvert Cliff's PRA.

Seals fail for many reasons, however, the seal failure probability is increased if CCW is lost. According to NUREG/CR 4948 "Technical Findings Related to Generic Issue 23: Reactor Coolant Pump Seal Failure," when full credit is given for the fourth (vapor seal) stage a negligible core damage frequency is obtained.

2.2.11 Summary

The RCP is a motor driven single stage centrifugal pump that provides forced circulation of reactor coolant. Four pumps, two per loop, are installed in the RCS. Reactor coolant from the steam generators enters the bottom of the pump through the pump suction piping and is pumped to the reactor vessel by the centrifugal force of the impeller. The leakage of coolant along the shaft of the pump is minimized by a seal assembly consisting of three series mechanical seals and a vapor seal.

The RCP motor is a squirrel-cage 13.8 kV motor, powered from non-vital ac buses. The motor contains a flywheel that functions to increase flow coast down time and an anti-reverse rotation device that minimizes reverse flow through an idle pump and thereby reduces motor starting current.

Table 2.2-2 Reactor Coolant Pump Design Data

Number	4
Type	Vertical, limited leakage, centrifugal
Shaft seal, type, number	Mechanical, 4
Materials	
Stationary face	Carbon CCP-72
Rotating face body	ASTM-A-351 Gr. CF8
Rotating face ring	Titanium carbide
Design pressure	2500 psia
Design temperature	650°F
Normal operating pressure	2250 psia
Normal operating temperature	548°F
Design flow	81,200 gpm
Total dynamic head	243 ft.
Maximum flow (one pump operation)	120,000 gpm
Dry weight	141,000 lb.
Flooded weight	148,000 lb.
Reactor coolant volume	112 ft^3
Motor	
Voltage	13,800 Vac
Frequency	60 Hz., 3 phase
Horsepower/speed, hot	4500 hp/900 rpm (nominal)
Horsepower/speed, cold	6000 hp/900 rpm (nominal)
Service factor	1.15

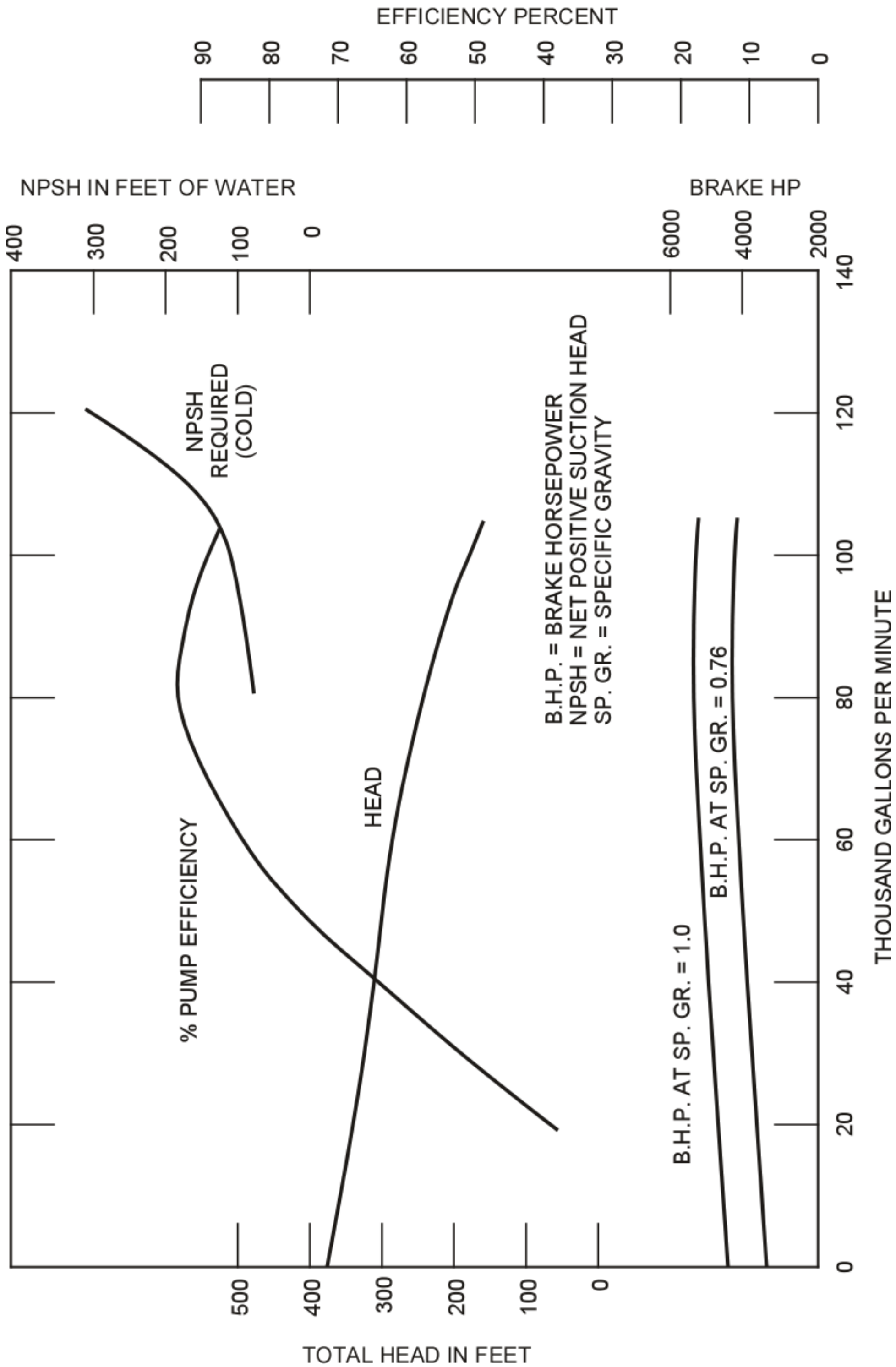

Figure 2.2-1 Reactor Coolant Pump Operating Curve

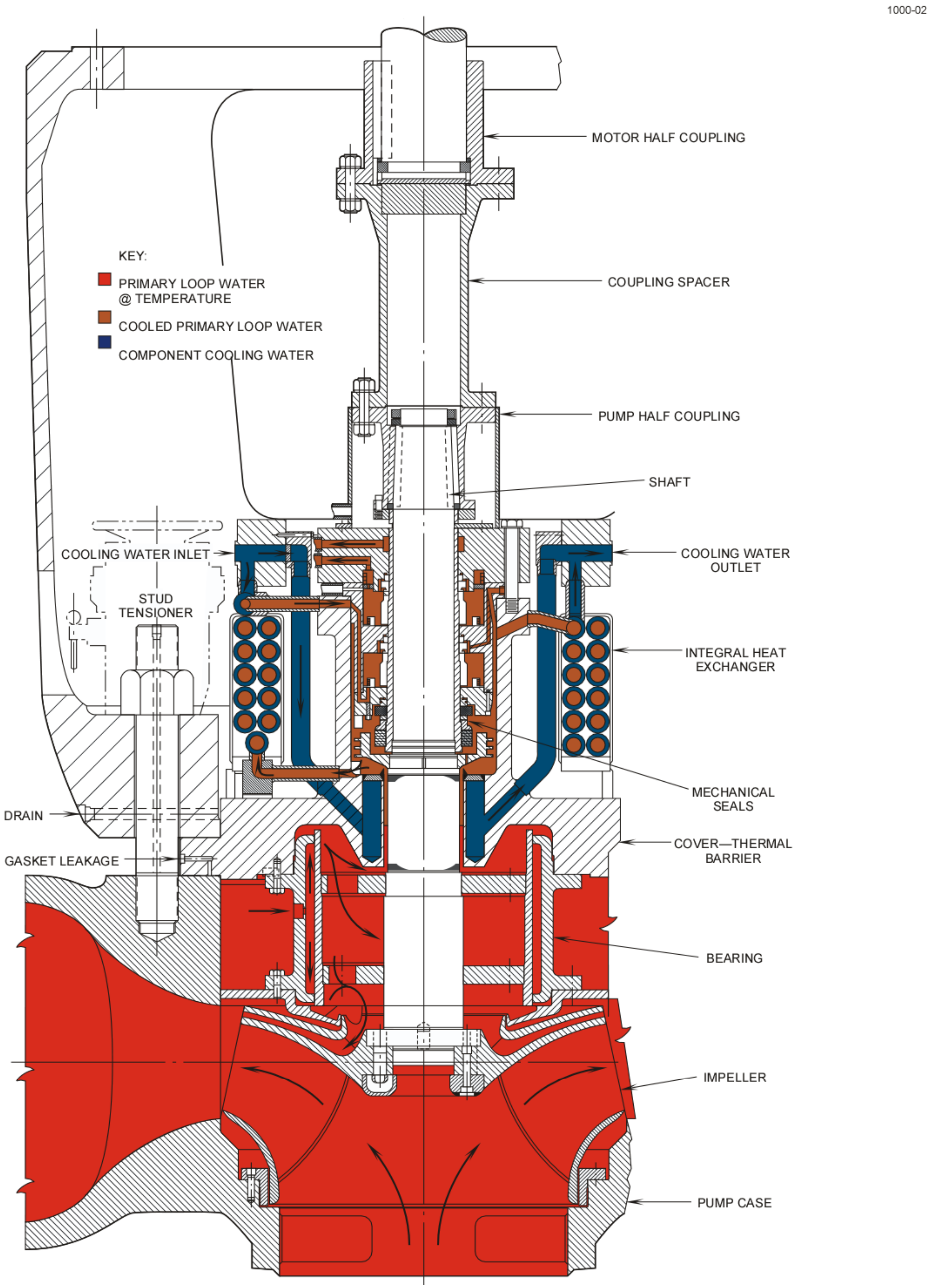

Figure 2.2-2 Reactor Coolant Pump Assembly

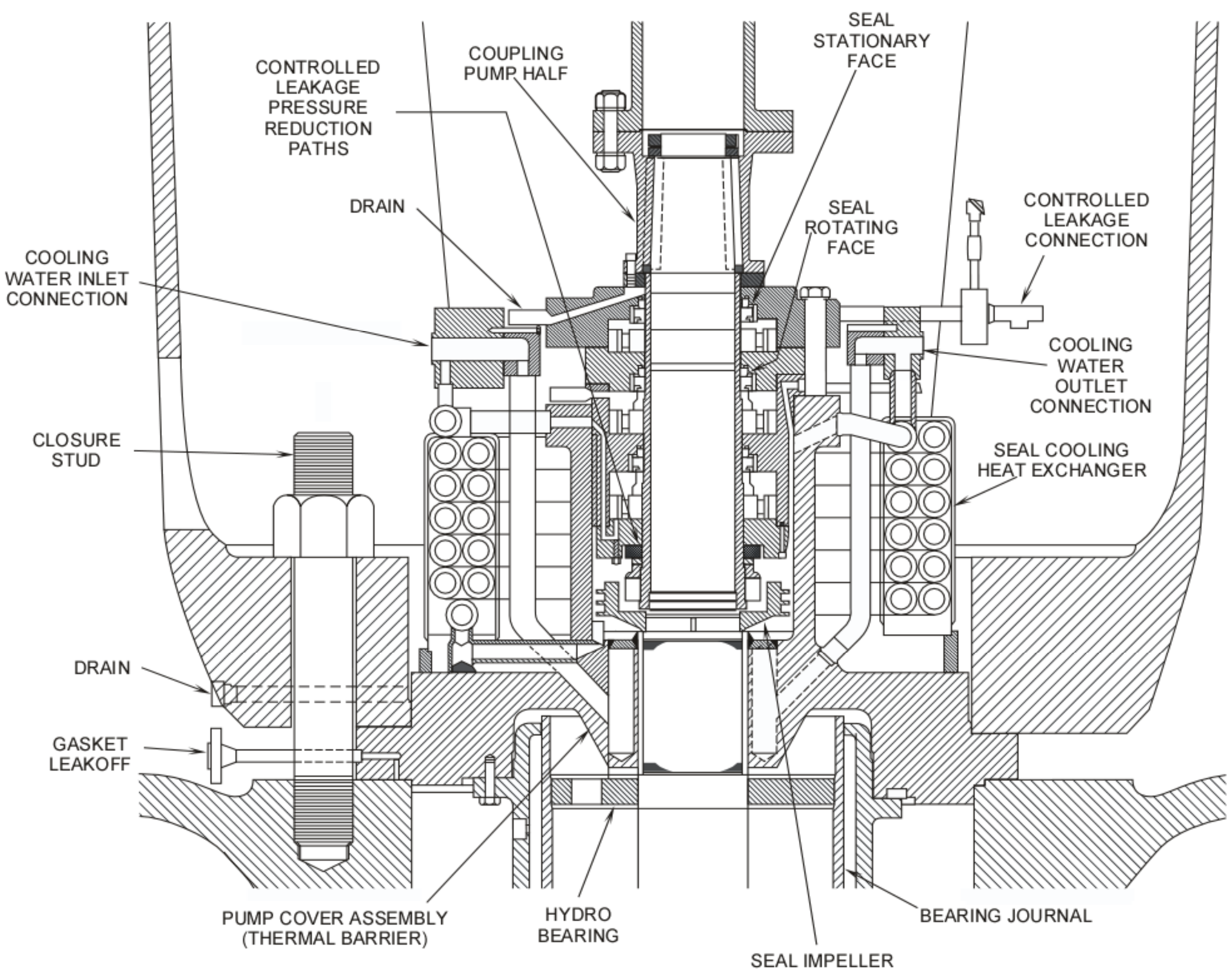

Figure 2.2-3 Reactor Coolant Pump Seal Assembly

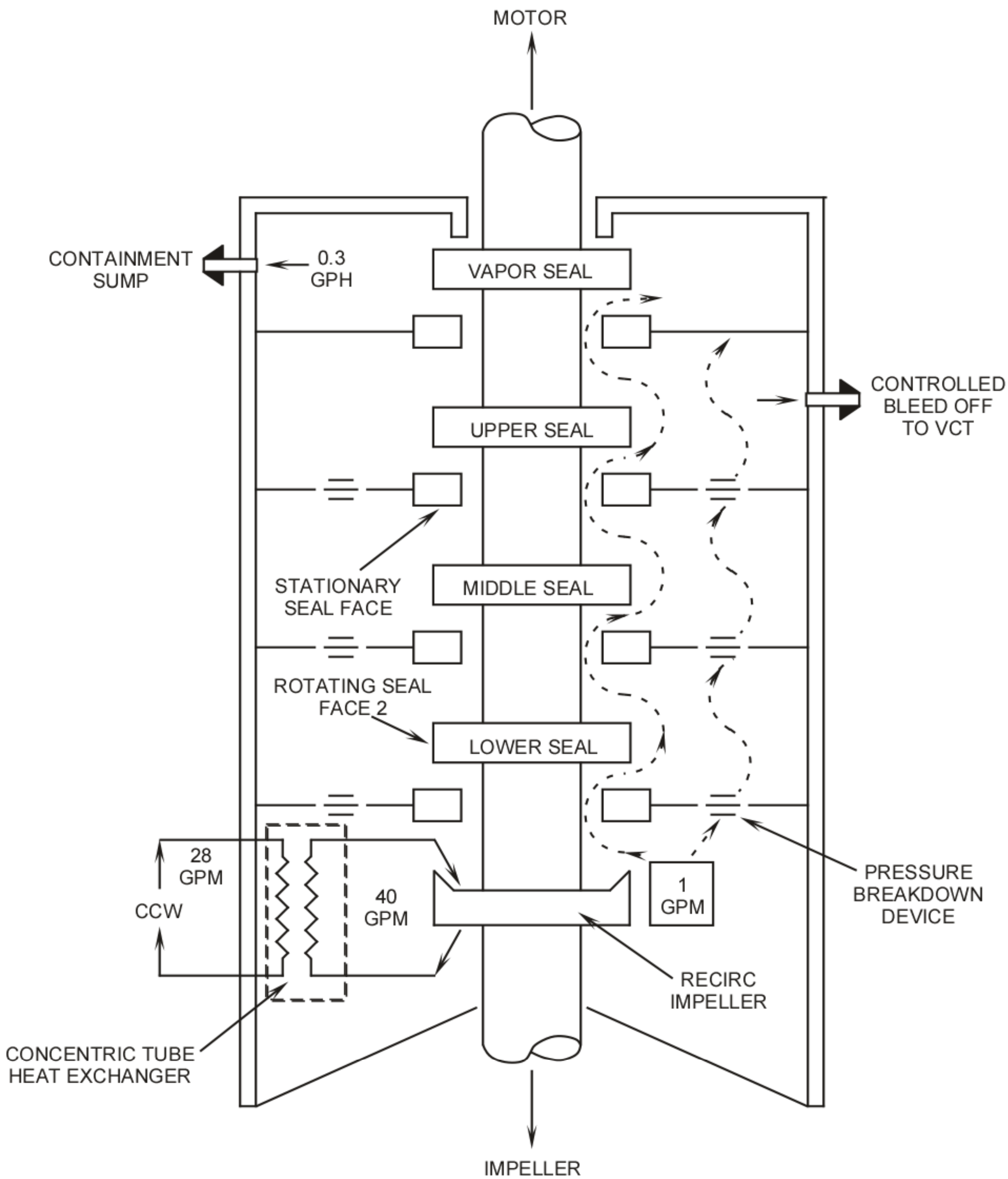

Figure 2.2-4 Simplified Seal Diagram

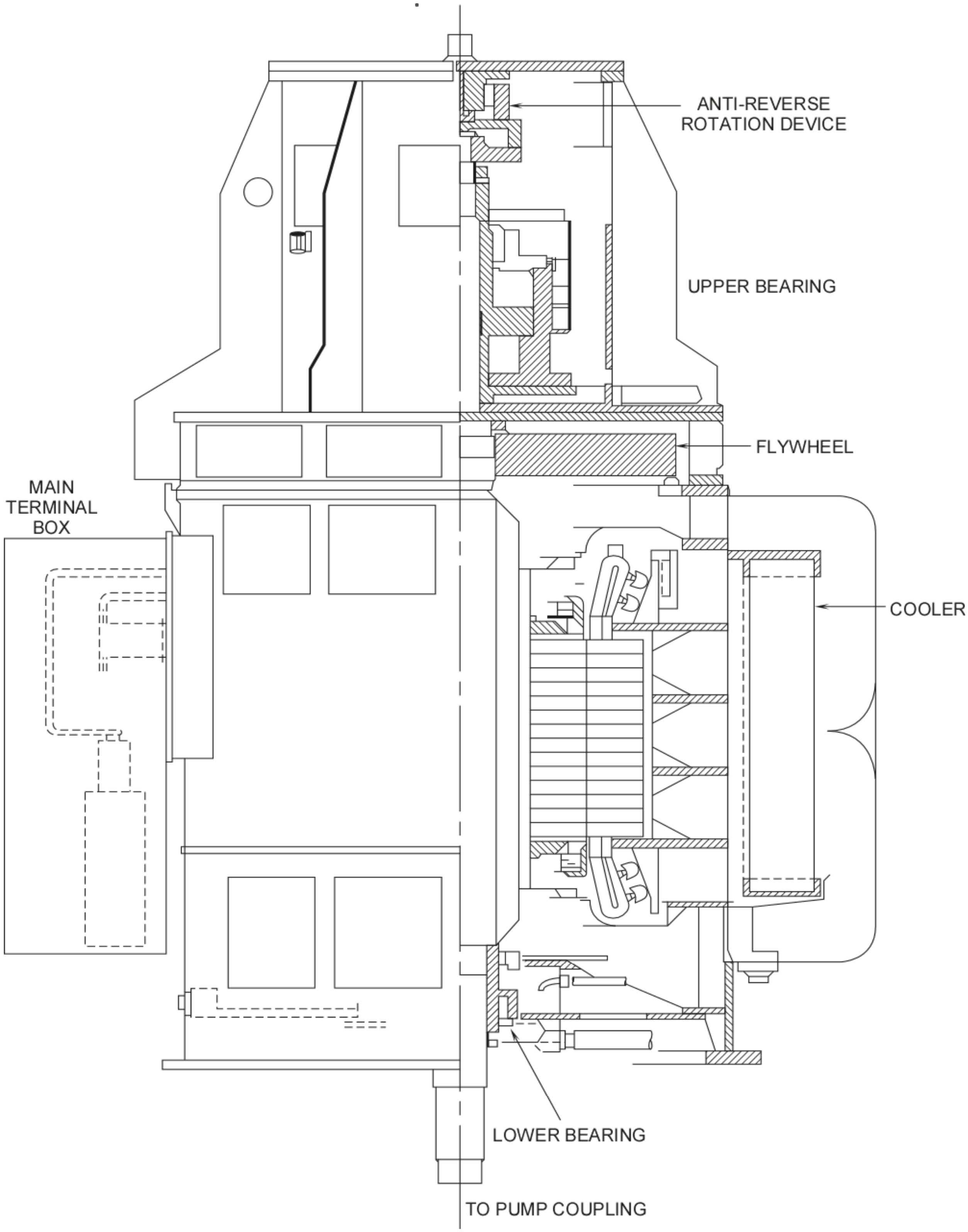

Figure 2.2-5 Reactor Coolant Pump Motor Assembly

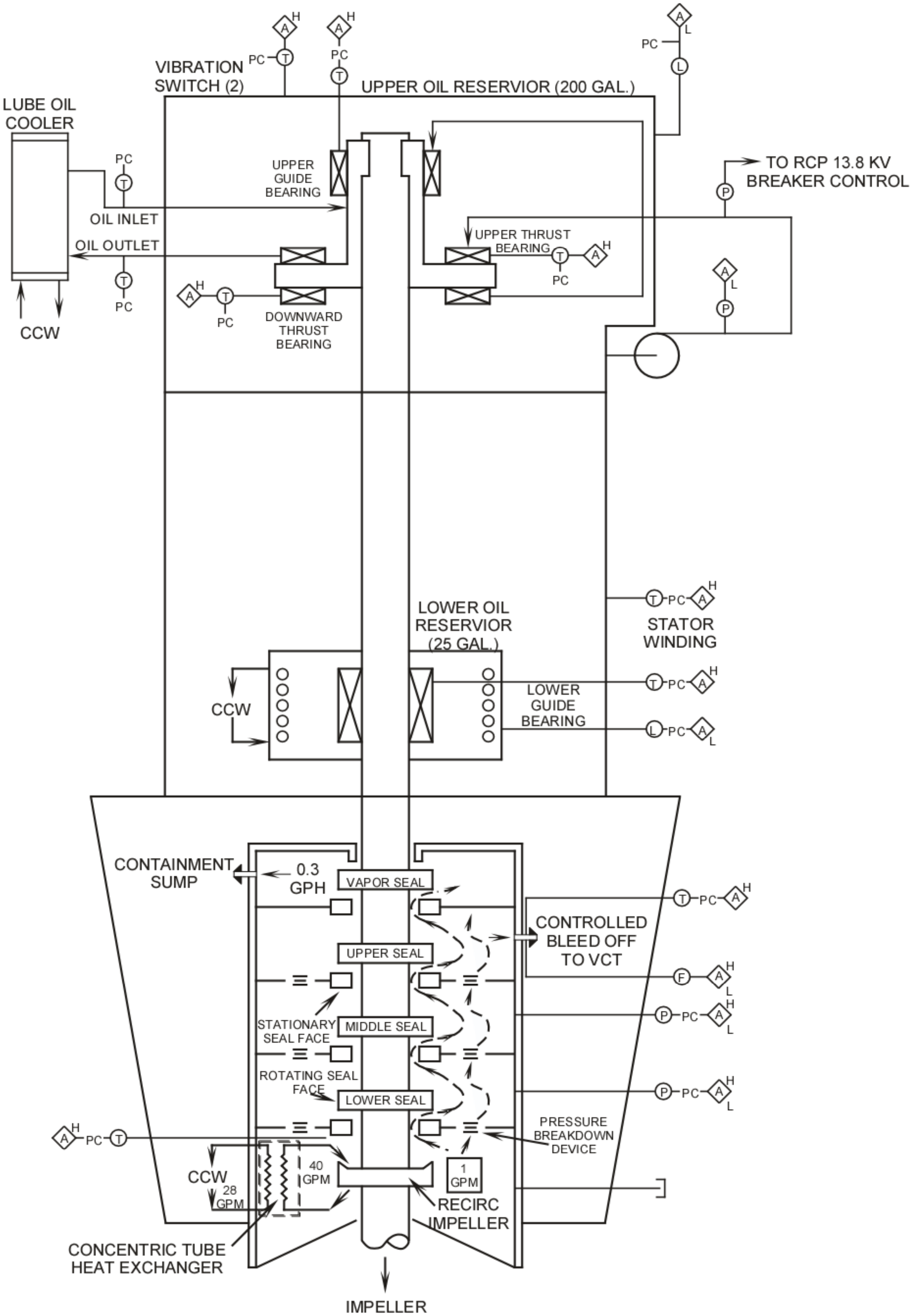

Figure 2.2-6 Reactor Coolant Pump Instrumentation